

Operational Use of EPOS to Increase the Science Value of EO-1 Observation Data

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Outline

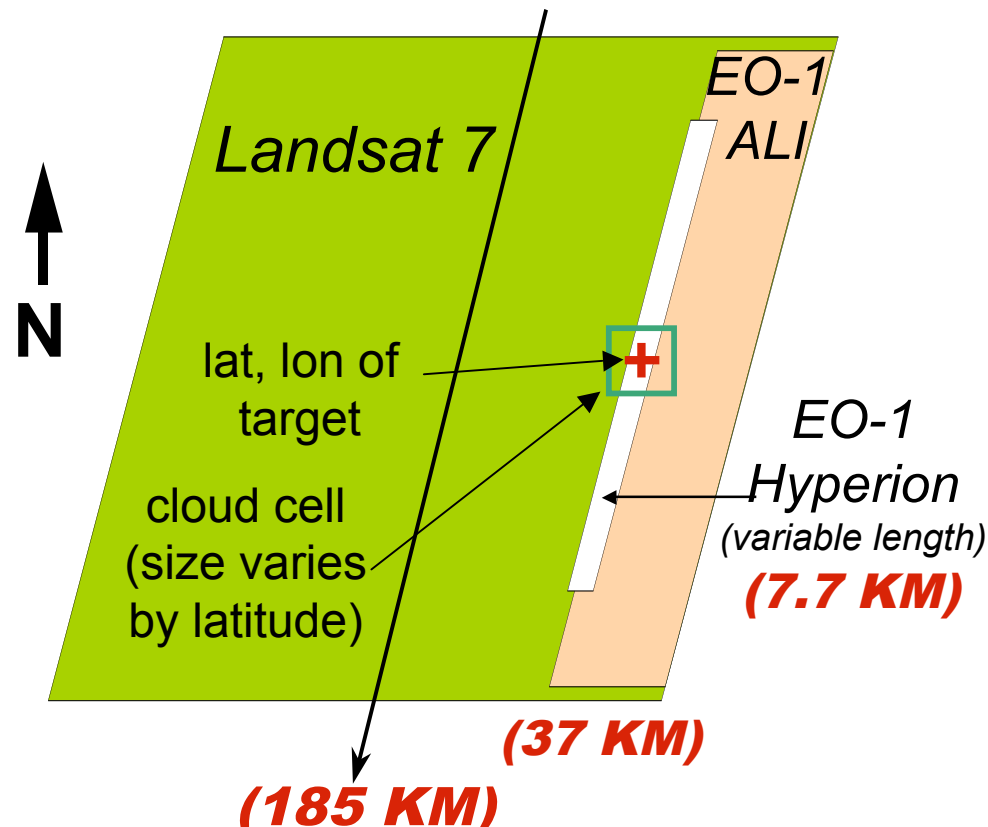
- **Concept of operations**
- **EO-1 overview**
- **EPOS for EO-1**
- **Cloud data**
 - WWMCA
 - SCFM
- **Use of cloud forecasts**
 - Current operations
 - Improving performance
- **Mixed-initiative visualization**

Concept of Operations

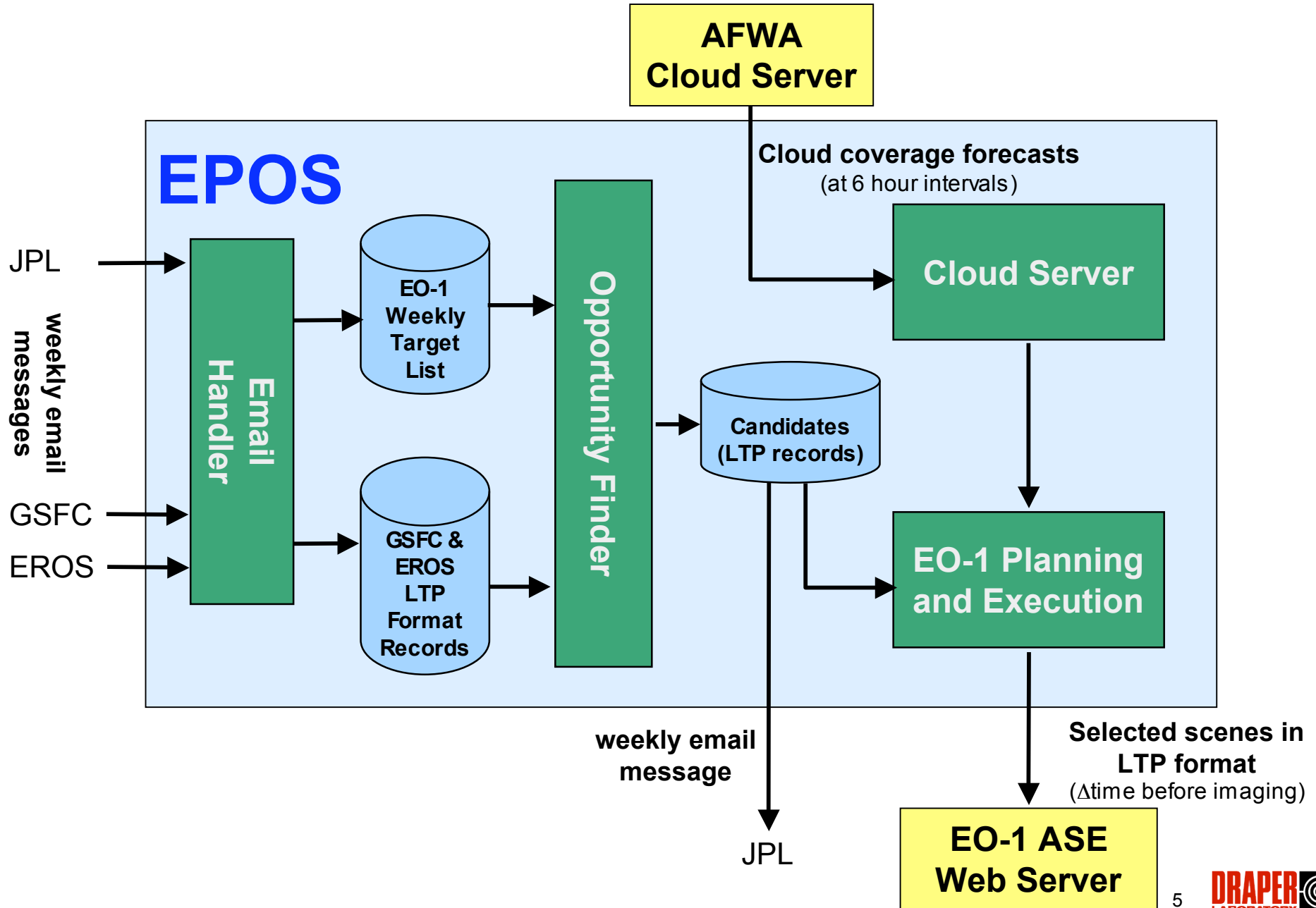
- **Exploit observation data gathered from one or more space-based sensors to cue the dynamic replanning and tasking of other space-based sensors in a sensor web**
- **In previous ESTC papers we described EPOS (Earth Phenomenon Observing System) technology that can dynamically replan for 105 satellites/sensors and 1450 targets in real time**
- **In ESTC 2005, we presented EPOS' real-time optimized planning capability for EO-1**
 - Evaluated in simulation
 - Modeled: onboard storage, satellite maneuverability, target priorities, and *cloud forecasts*
- **Currently we are supporting EO-1 missions operations**
 - Emphasis is on optimized utilization of cloud cover forecasts
 - EPOS is used to select targets that have higher likelihood of little or no cloud cover, resulting in higher quality images over the long run
- **Extending original concept to include coordinated mission management for a fleet of autonomous surface vessels**

EO-1 Imaging

- **Operational instruments**
 - *ALI* (Advanced Land Imager) bands overlap Landsat's
 - *Hyperion* is a high resolution hyperspectral imager
- **EO-1 has capabilities for off-nadir pointing**
 - For off-nadir pointing, EO-1 is slewed
- **EO-1 and Landsat 7 Descending Orbit Ground Tracks**



EPOS for EO-1 Functional Architecture

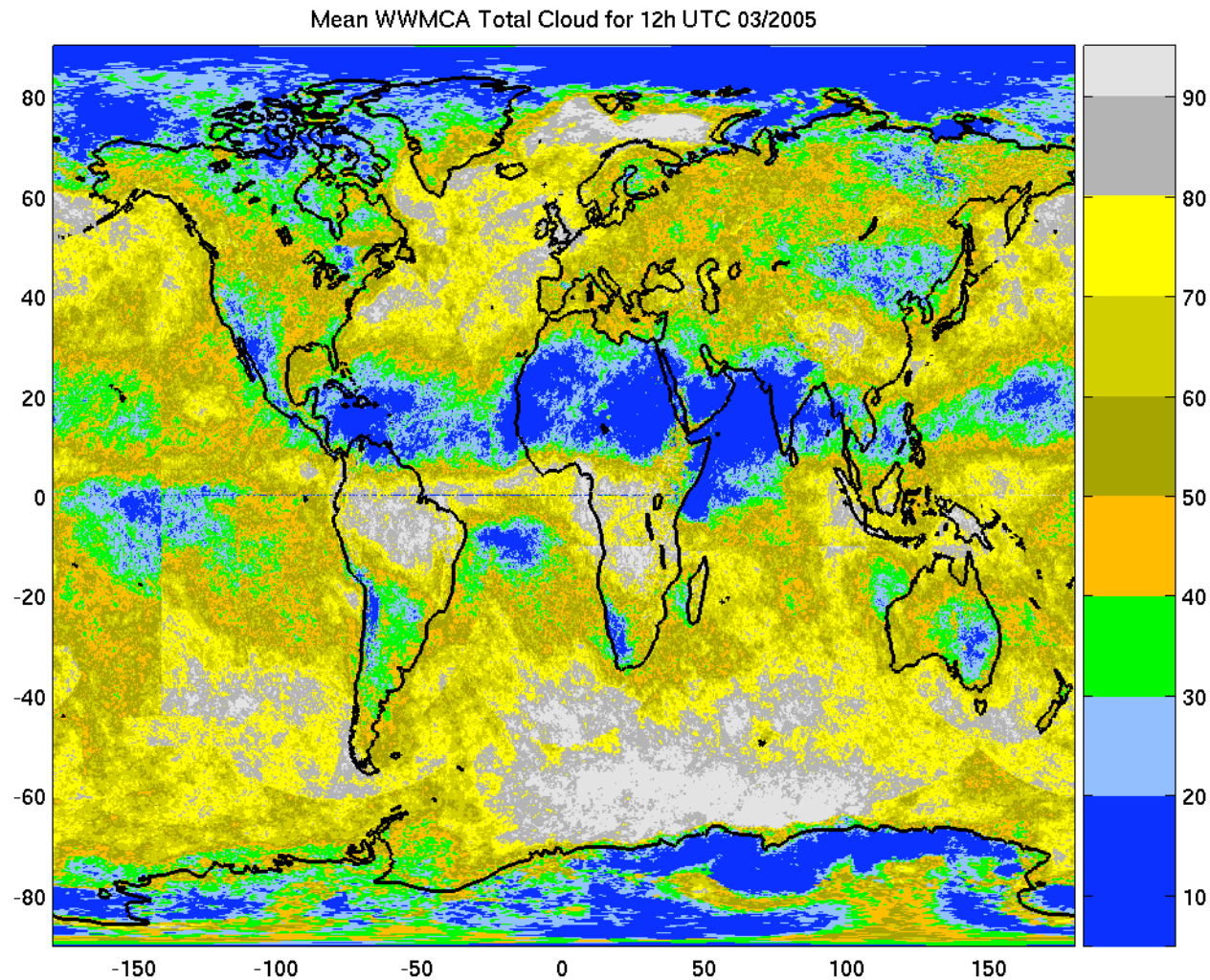


Cloud Cover Data Overview

- **We are currently automatically accessing cloud data from an AFWA (Air Force Weather Agency) server 24/7**
 - Current cloud data (WWMCA = World-Wide Merged Cloud Analysis) is received every hour
 - Forecast cloud data (SCFM = Stochastic Cloud Forecast Model) is received every six hours, approximately 1.5 hours after the nominal time of the forecast
- **We process the data and store in the EPOS Cloud Server**
 - Queries by visualization and planning allow access to any of the current or forecast processed data sets

Average Cloud Cover – WWMCA

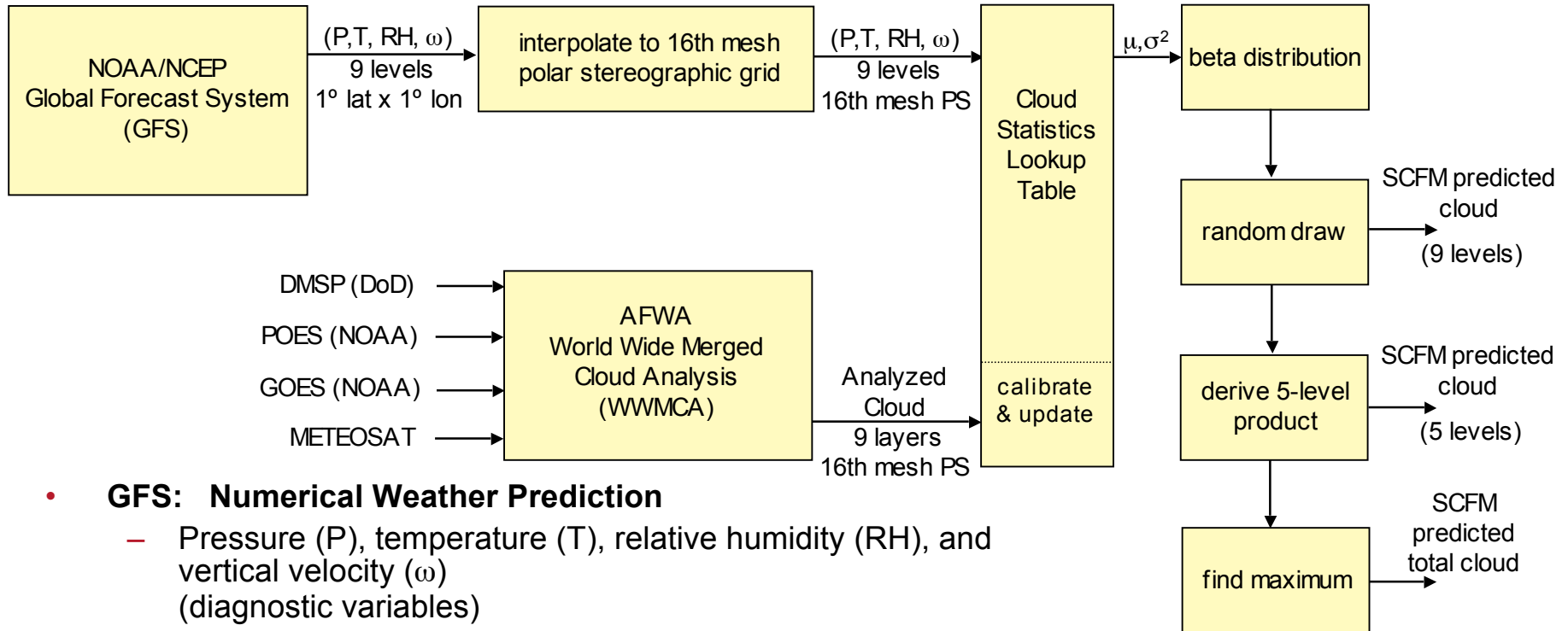
1200 UTC March 2005



Stochastic Cloud Forecast Model (SCFM)

- **SCFM forecasts are generated 4 times per day at the Forecast Generation Time (FGT): 0000, 6000, 1200, 1800 UTC (GMT/Zulu)**
- **Each forecast is distributed as 29 gridded binary (GRIB) files**
 - 1200 UTC = 0800 EDT => reception of forecast data starting at about 9:30 AM
 - Forecasts are given for 3-hour periods over an 84 hour time horizon into the future
- **Each file includes seven 721x1440 data matrices (0.25° latitude x 0.25° longitude)**
 - Predicted total cloud cover
 - Predicted cloud cover at each of 5 pressure (altitude) levels
 - Thunderstorm potential indicator
- **We use the predicted total cloud cover**

SCFM Overview



- **GFS: Numerical Weather Prediction**
 - Pressure (P), temperature (T), relative humidity (RH), and vertical velocity (ω) (diagnostic variables)
- **WWMCA: Analysis of Satellite Observations**
 - Historical cloud data
- **SCFM: Stochastic Forecast**
 - Cloud density is a beta-distributed random variable
 - Obtain mean and variance by accessing a lookup table using forecast data from GFS
 - Estimate beta distribution parameters using method of moments
 - Obtain forecast by random draw

SCFM Processing

- **SCFM processing for each pressure level is as follows:**
 - Predicted pressure (P), temperature (T), relative humidity (RH), and vertical velocity (ω) are obtained on a 1° latitude x 1° longitude grid from NOAA's Global Forecast System (GFS)
 - Use (P,T,RH, ω) to obtain mean μ and variance σ^2 of cloud density from a lookup table
 - **Lookup table is constructed by AFWA using a historical database of World Wide Merged Cloud Analysis (WWMCA) data**
 - **Separate mean and variance are obtained for each location**
 - Obtain predicted cloud cover at each location by taking a random draw from a beta distribution whose mean and variance are the lookup μ and σ^2 for the location
- **SCFM predicted total cloud cover for a given location is the maximum of the cloud covers predicted for pressure (altitude) levels at that location**

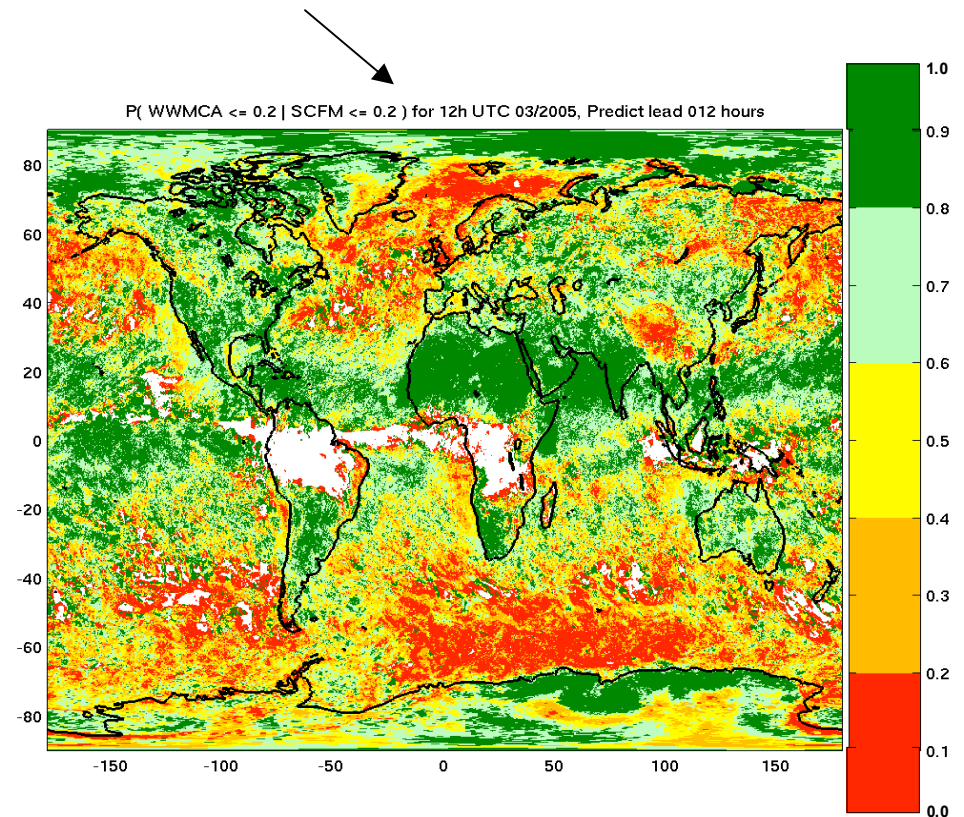
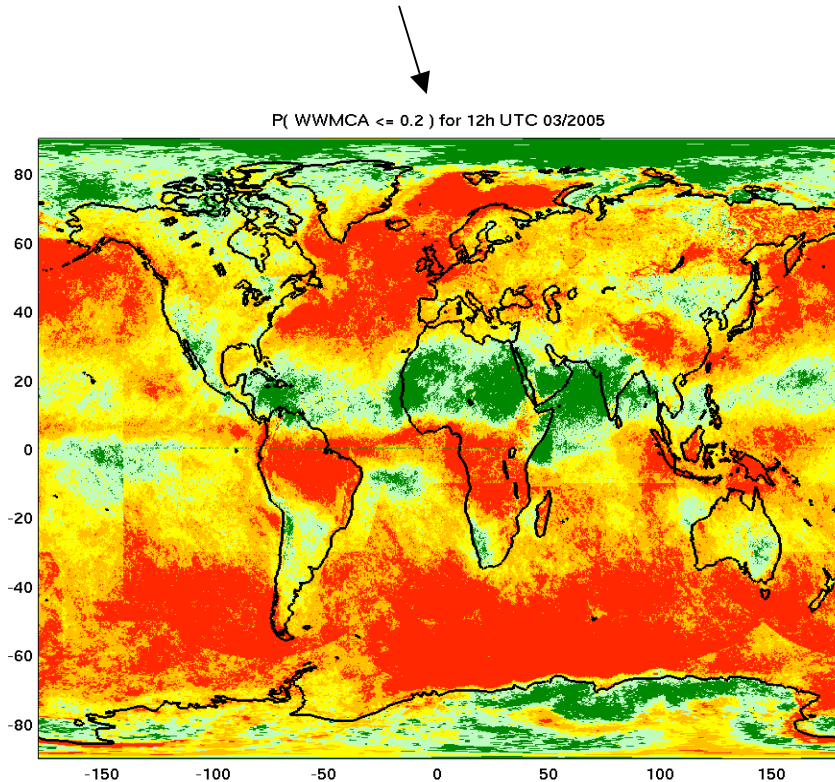
Cloud Forecast in Current Operations

- Typically, on each orbital revolution there is a primary (pre-picked) and one or two alternative targets in the EO-1 target list
- Current NASA rule used:
 - Select the primary target if its cloud cover is forecast to be $\leq 20\%$
 - Select the primary if the cloud cover is forecast to be $\geq 80\%$ for all targets
 - Select the primary if there is less than 20% difference between the forecast for the primary's cloud cover and any alternate target's cloud cover
 - Otherwise, select the best (with smallest predicted cloud cover) alternate

Result: Increased Likelihood of High Quality* Scenes

Illustrated in the 12-Hour SCFM forecast for March 2005

- $P(\text{cloud cover} \leq 20\%)$
- $P(\text{cloud cover} \leq 20\% \mid \text{forecast cloud cover} \leq 20\%)$



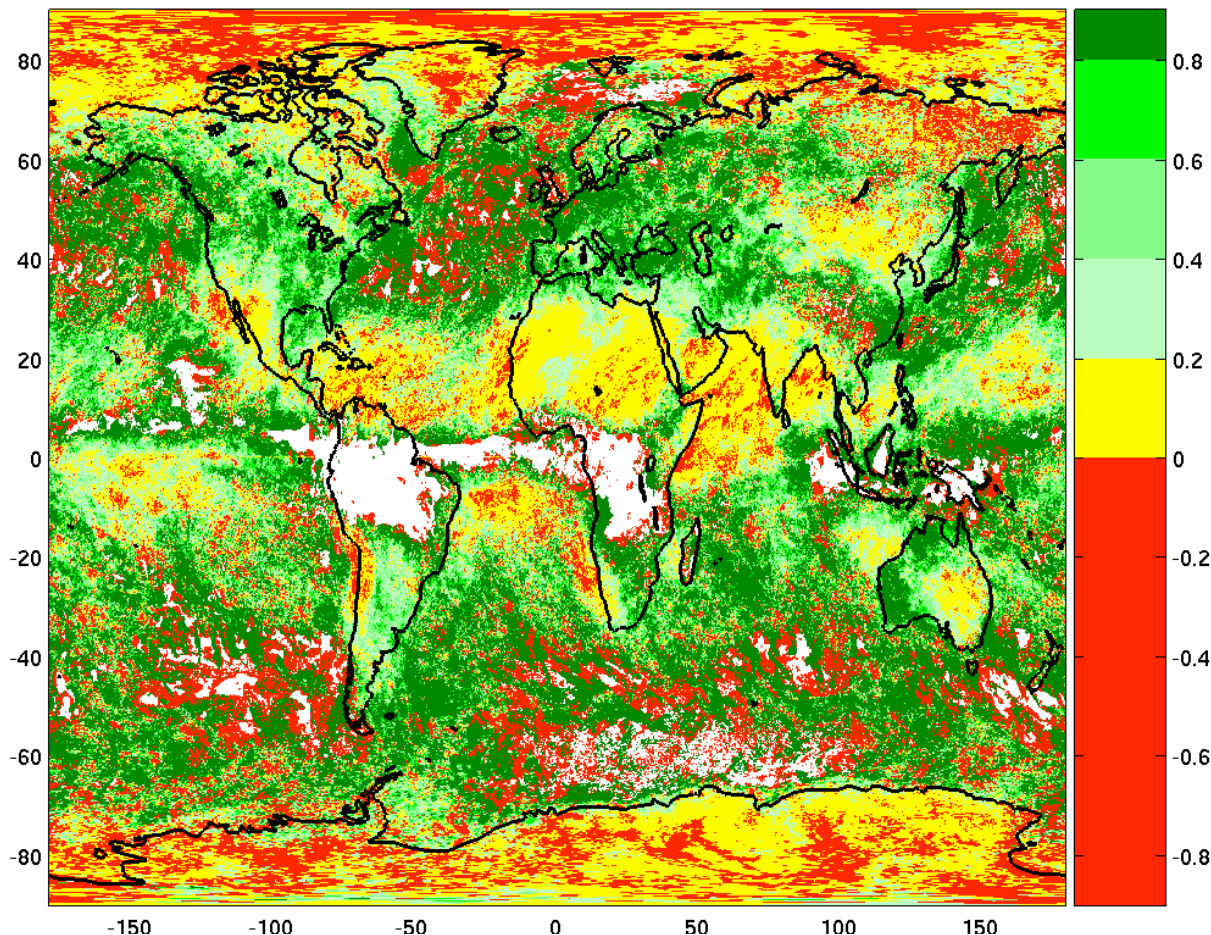
* A high quality scene is one with (total) cloud cover $\leq 20\%$
(20% is an input parameter)

Improving the Use of the Cloud Forecast

*K = predicted increase in relative frequency of high quality scenes \Rightarrow
a reduction in the expected number of images that need to be taken to get a high quality scene*

$$(P(\text{cloud cover} \leq 20\% \mid \text{forecast cloud cover} \leq 20\%) - P(\text{cloud cover} \leq 20\%)) / P(\text{cloud cover} \leq 20\%)$$

$(P(W \leq 0.2 \mid S \leq 0.2) - P(W \leq 0.2)) / P(W \leq 0.2)$ 12h UTC 03/2005, Predict lead 012 hours



Example:

$$P(CC \leq 20\%) = 0.33$$

$$P(CC \leq 20\% \mid FCC \leq 20\%) = 0.50$$

$$\text{Increase} = (0.50 - 0.33) / 0.33 = 52\%$$

Let N = number of images it takes to get a high quality scene

In this example, the expected number to achieve a high quality scene is reduced from $E(N) = 3$ to $E(N \mid FCC \leq 20\%) = 2$

CC = cloud cover

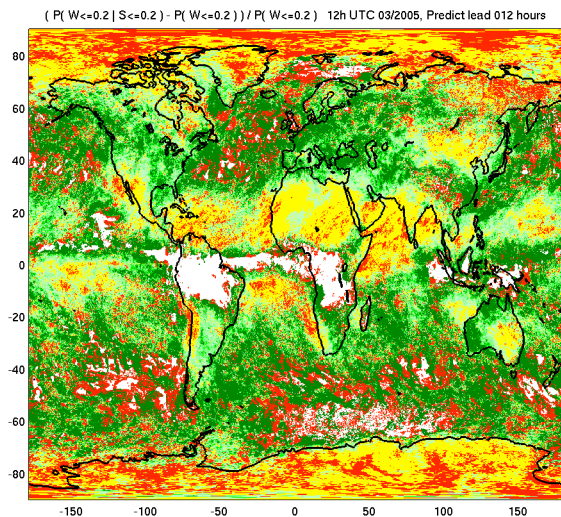
FCC = forecast cloud cover

**March 2005 Data
12 Hour Forecast**

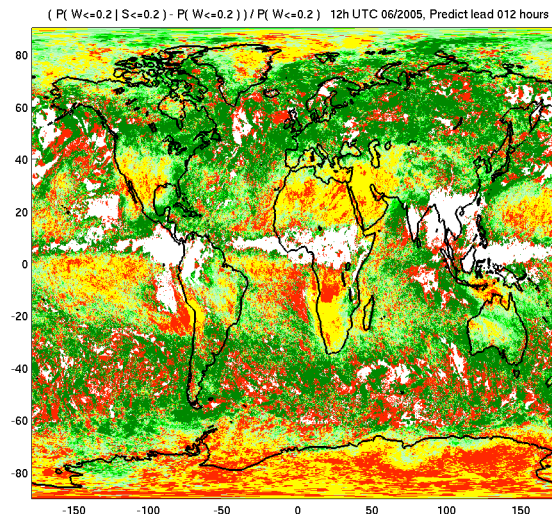
Predicted Increase in High Quality Scenes a Function of Month and Location

- Developed a database with almost 1 TB of WWMCA and SCFM cloud data from which all the relevant cloud statistics are calculated
- Developed a database to store the cloud statistics
- Data collection is ongoing

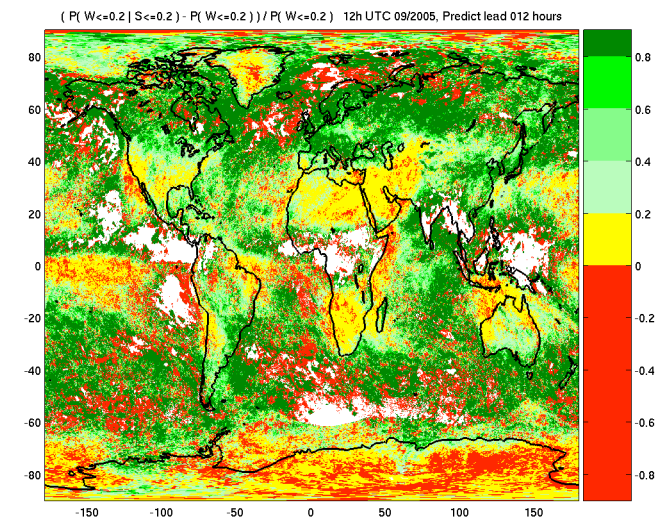
March 2005



June 2005



September 2005



$$K = (P(CC \leq 20\% \mid FCC \leq 20\%) - P(CC \leq 20\%)) / P(CC \leq 20\%)$$

12 hour forecast used

CC = cloud cover

FCC = forecast cloud cover

Evaluation of Metric in EO-1 Operations (1)

We have been studying how much we can improve performance by using the metric in the target selection process for EO-1

- **Results here based on a list of 389 EO-1 targets between July 20, 2005, and April 20, 2006**
- **Used historical EO-1 ephemeris data obtained from the Air Force SpaceTrack web site to determine possible realistic viewing opportunities**
- **Used historical SCFM total cloud forecast that would have been available at least 8 hours before each viewing opportunity**
 - 8 hours is the lead time for target selection currently being used in our operations with EO-1
 - Compared with the corresponding WWMCA values

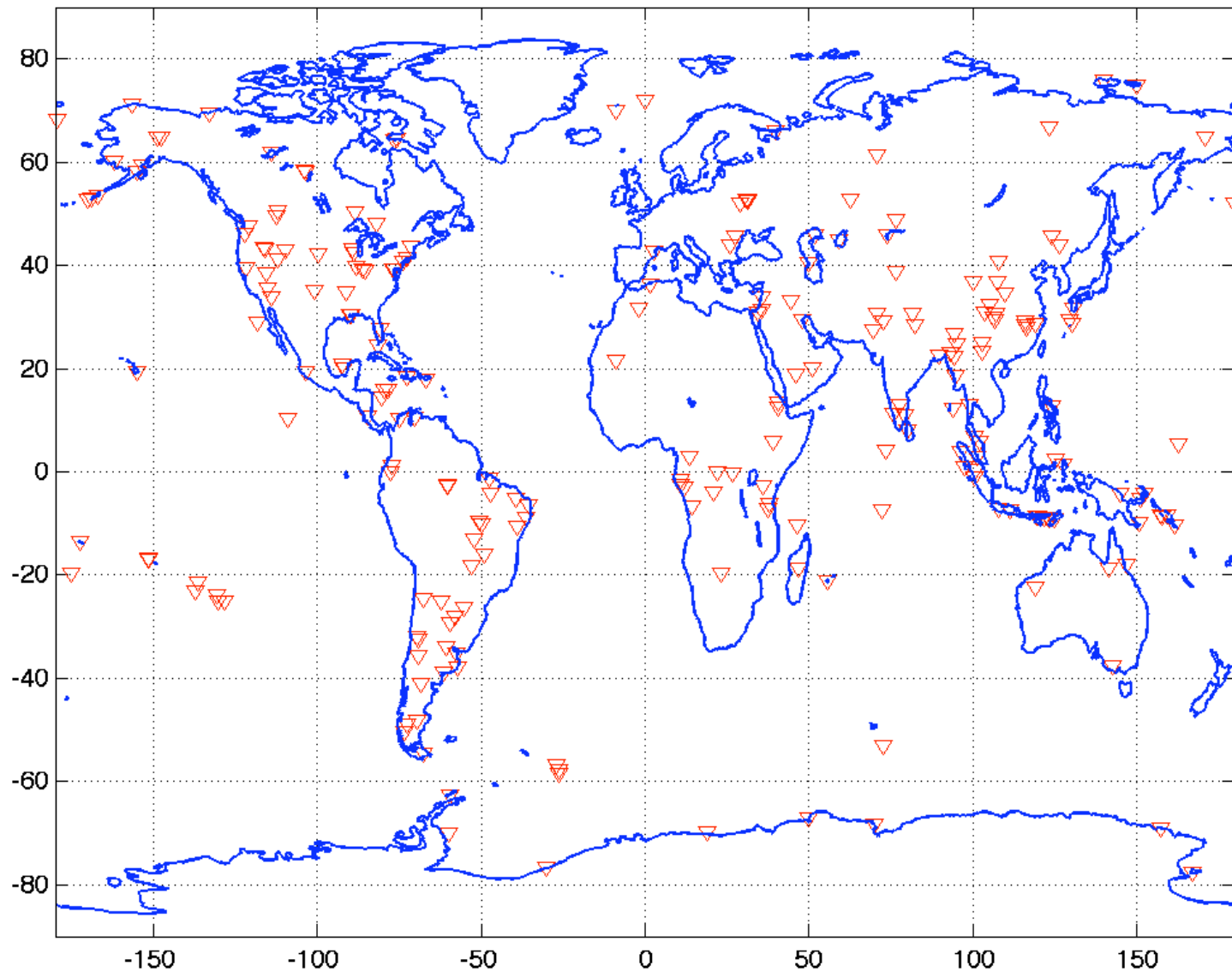
Evaluation of Metric in EO-1 Operations (2)

- On March 1 and 2 of 2006, 265 of the 389 targets were visible to EO-1
 - 30 of the targets did not have sufficient cloud data for analysis
- The predicted increase in the relative frequency of high quality scenes, was calculated by:
 - $K = (P(CC \leq 20\% \mid FCC \leq 20\%) - P(CC \leq 20\%)) / P(CC \leq 20\%)$
 - CC = cloud cover
 - FCC = forecast cloud cover
 - If $K > 0$, then the forecast improves the likelihood of getting a high quality scene

CC = cloud cover

FCC = forecast cloud cover

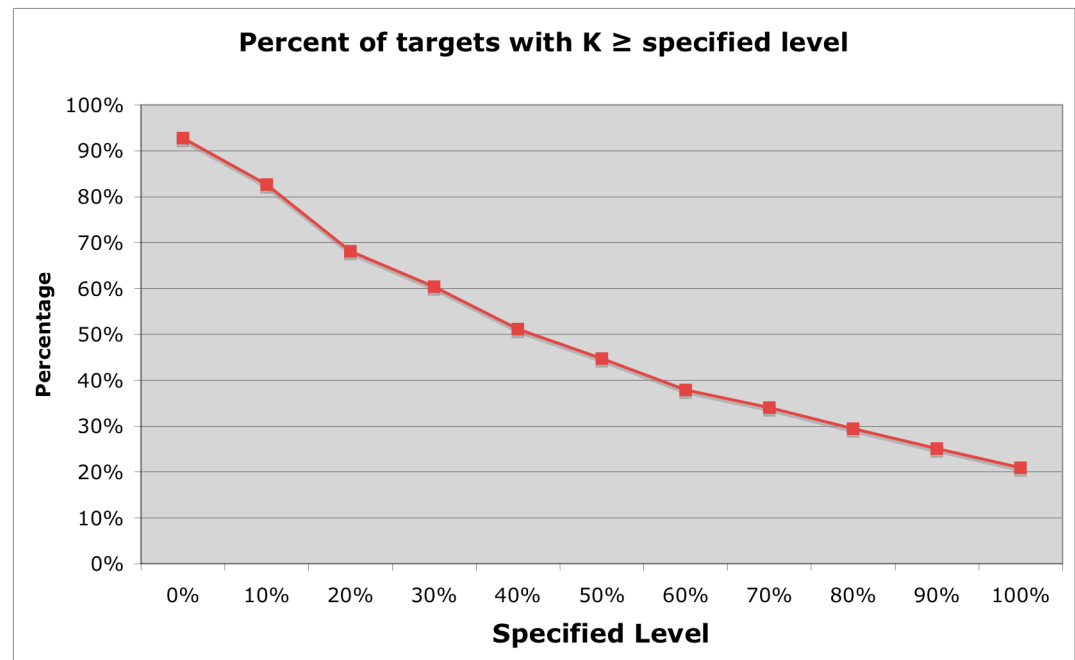
EO-1 Viewing Opportunities 1-2 March 2006



Evaluation of Metric in EO-1 Operations (3)

- Of the 235 targets with sufficient data for calculation of K, we found the results given below
- Note that 7.2% of the time, the forecast resulted in a reduction in the likelihood of getting a high quality scene

| Specified level = SL | Number of targets with $K \geq SL$ | Percent of targets with $K \geq SL$ |
|----------------------|------------------------------------|-------------------------------------|
| 0% | 218 | 92.8% |
| 10% | 194 | 82.6% |
| 20% | 160 | 68.1% |
| 30% | 142 | 60.4% |
| 40% | 120 | 51.1% |
| 50% | 105 | 44.7% |
| 60% | 89 | 37.9% |
| 70% | 80 | 34.0% |
| 80% | 69 | 29.4% |
| 90% | 59 | 25.1% |
| 100% | 49 | 20.9% |



Current Status in Our Support of EO-1 Operations

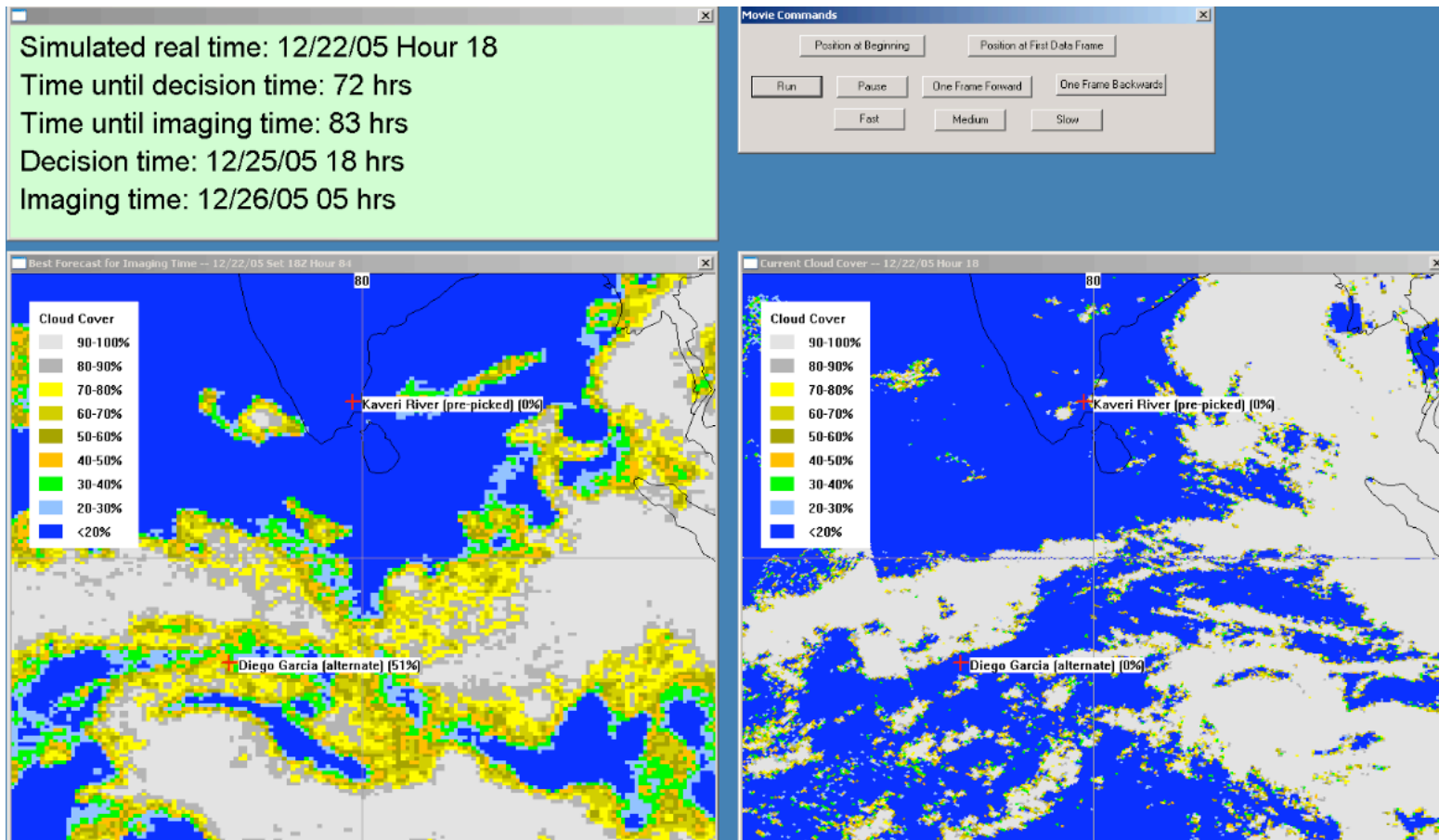
- **Data mining historical SCFM and WWMCA cloud data produces a measure (the K metric) of the confidence we have in the cloud forecast for a given target location and time of imaging**
 - Can be used to improve the science value gained over the long term from EO-1 observations
- **Within a week or two we will have finished our integrated testing of new software that uses the K metric in target selection**
 - We will be using it within the operational system starting in July
- **We have developed a simulation environment in which we are evaluating a proposed set of new rules for tasking EO-1**
 - Goal is to find the statistically best rule along with optimized parameter values

Mixed-Initiative Visualization Capabilities

- **Mixed-initiative visualization capabilities for Human-Machine Collaborative Decision Making aid in the EO-1 target selection process**
- **Evolving cloud locations and their movement are shown through the visualization of cloud data (both WWMCA and SCFM) over the targets as two key event milestones approach**
 - The decision time at which either the primary or an alternate target is selected
 - The imaging time over the targets
- **An operator is able to visually assess complex cloud patterns and their movement, aiding the selection of a high quality scene**

12/25/05 Opportunity: Initial Forecast, 83 Hours before Imaging

Kaveri River (primary) or Diego Garcia (alternate)



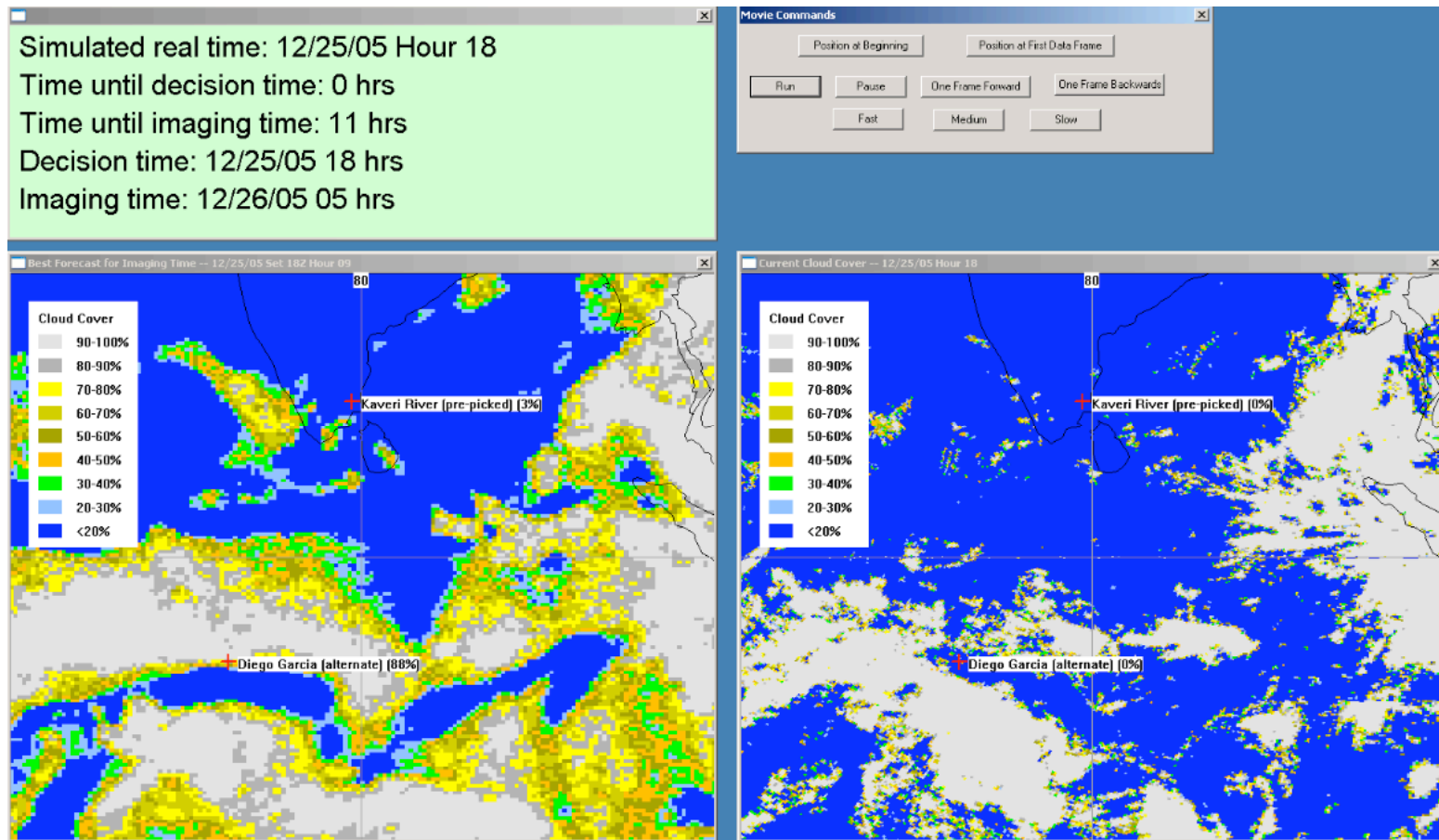
Cloud cover forecasts from 83 hours before imaging to 8 hours (= decision time) before imaging

Actual cloud cover at time of corresponding forecast

12/25/05 Opportunity:

Decision Time, Primary Target Remains Best Option

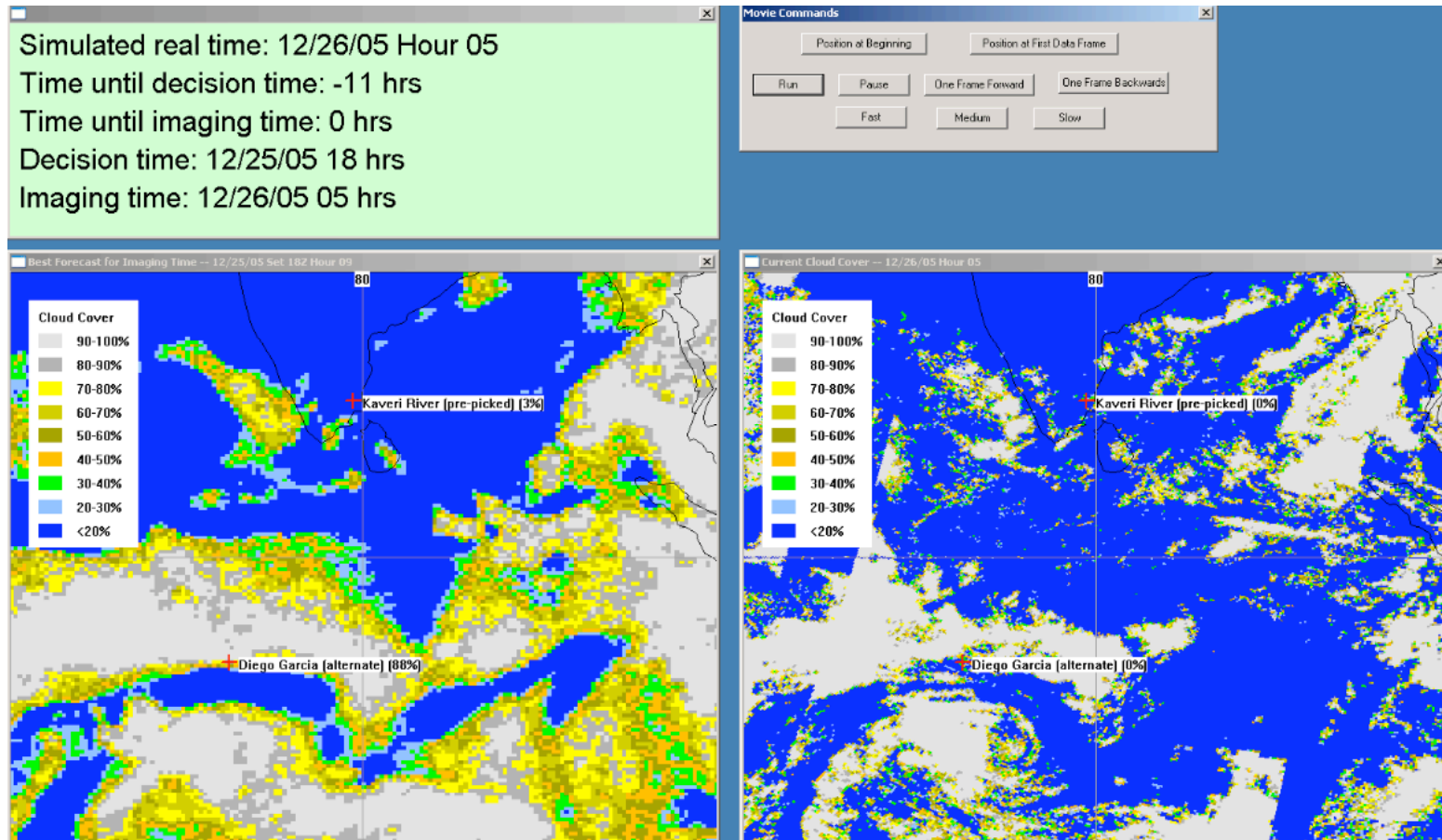
At Decision time the pre-picked primary target was predicted to be significantly less cloudy than the alternate target (3% vs 88%). Alternate not sent.



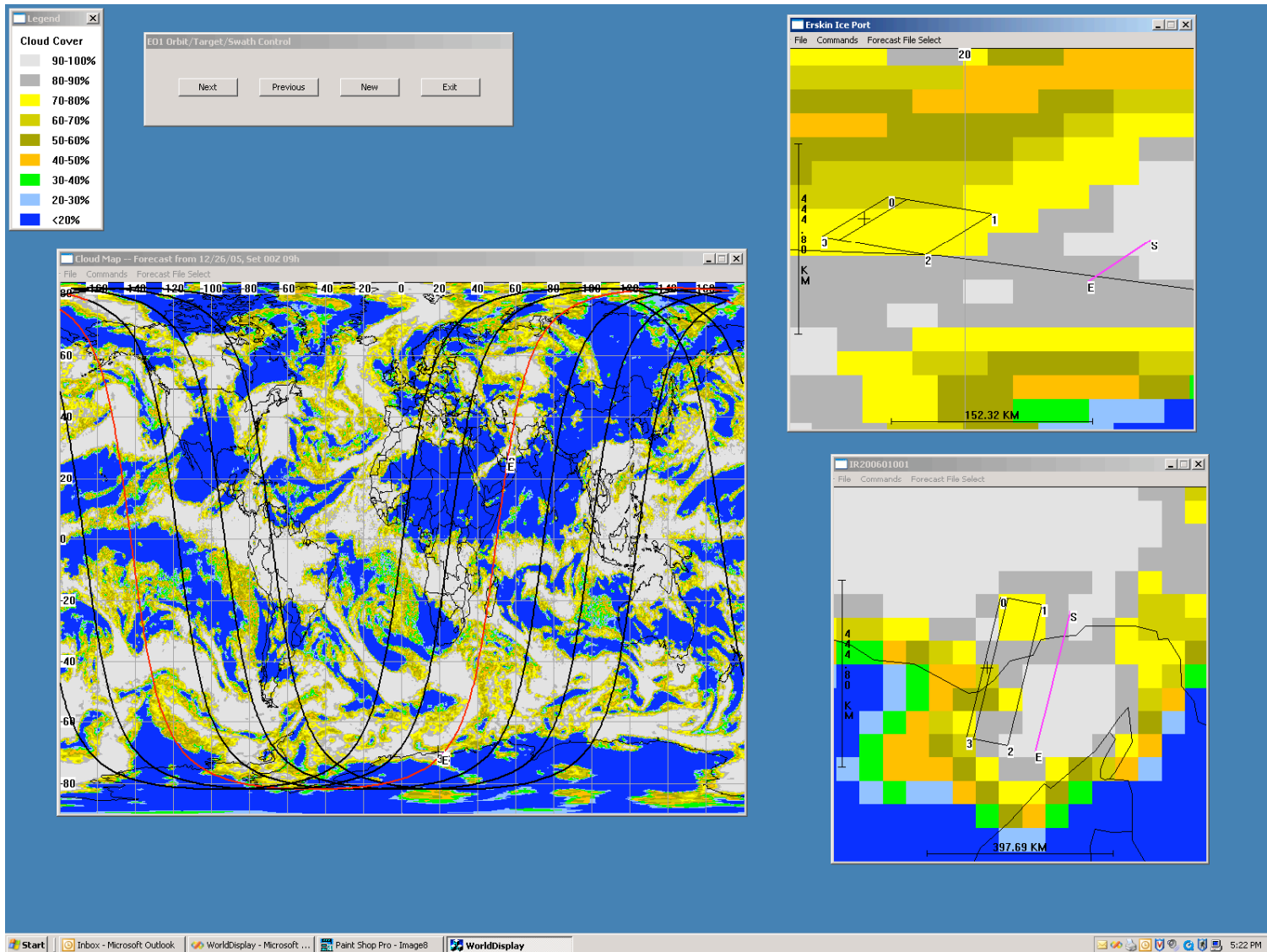
Cloud cover forecasts from 84 hours before imaging to 11 hours (= decision time) before imaging

Actual cloud cover at time of corresponding forecast

12/25/05 Opportunity: Imaging Time, Forecast Holds, Primary Target Clear



Swath Visualization of Targets



December 26, 2005

Summary/Conclusion

- **There is significant value in utilizing cloud forecasts in the tasking of EO-1**
 - Improved by data mining of historical forecast performance data
- **The cloud forecast access capability we have developed is mature and available for use in other EOS systems**
- **Cueing of sensors not limited to cloud forecasts**
- **Sensors not limited to being space-based**
- **Capability fits well into the concept of a sensor web**